

Biological Control of *Anastrepha* spp. (Diptera: Tephritidae) in Mango Orchards through Augmentative Releases of *Diachasmimorpha longicaudata* (Ashmead) (Hymenoptera: Braconidae)

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Diachasmimorpha longicaudata (Ashmead) parasitoids were released by air on a weekly basis over 1600 ha of commercial mango orchards, backyard orchards, and patches of native vegetation, at a density of ca. 940 parasitoids/ha. Releases were made during 2 consecutive years, beginning at flower onset and lasting until the end of the production cycle. Two areas, 7 km apart, were compared. In one area parasitoids were released, whereas the other area was used as a control. During the 2nd year treatments were reversed. Fruit was sampled in commercial mango orchards and in backyard orchards to assess levels of parasitism in fruit fly larvae. Highly significant differences in percentage parasitism were found in release and control zones in backyard orchards. Furthermore, trapping results indicated that *D. longicaudata* releases were associated with ca. 2.7-fold suppression of *Anastrepha* spp. populations in backyard orchards. Results suggest that suppression might be affected by environmental conditions and by the parasitoid:fly ratio achieved. *Anastrepha obliqua* McQuart populations were suppressed more effectively by use of parasitoids than those of *Anastrepha ludens* Loew, perhaps due to the type of host fruits used by each species. Augmentative parasitoid releases in marginal areas surrounding commercial orchards (backyard orchards, wild vegetation) can substantially suppress fly populations. Through this approach, the number of flies that later move into commercial orchards can be significantly reduced. Such a strategy, when combined with sound orchard management schemes, can allow growers to produce clean fruit without the need to resort to the widespread use of insecticides. © 2000 Academic Press

Key Words: *Diachasmimorpha longicaudata*; fruit flies; *Anastrepha ludens*; *Anastrepha obliqua*; biological control; augmentative releases; mango orchards.

INTRODUCTION

Biological control of fruit flies (Diptera: Tephritidae) has been attempted mainly with Opiinae braconid parasitoids (Hymenoptera). In several parts of the world, species of the genus *Diachasmimorpha* (= *Bio-steres* = *Opius*) have been introduced for the classical biological control of these pests (Wharton, 1989). For example, in Hawaii species such as *Diachasmimorpha longicaudata* (Ashmead) and *Diachasmimorpha tryoni* (Cameron) were successfully established during the early 1950s (Clausen *et al.*, 1965; Bess *et al.*, 1961; Wong *et al.*, 1984).

D. longicaudata is a solitary fruit fly endoparasitoid from the Indoaustralian region, where it parasitizes at least 14 species of flies in the genus *Bactrocera* (= *Dacus*) (Wharton and Gilstrap, 1983). Following introductions into different countries, *D. longicaudata* has been reported parasitizing *Anastrepha* spp., *Ceratitis capitata* (Wiedemann), and *Bactrocera dorsalis* (Hendel) (Wharton *et al.*, 1981; Wong *et al.*, 1984; Jirón and Mexzon, 1989; Aluja *et al.*, 1990; Eskafi, 1990; Baranowsky *et al.*, 1993; López *et al.*, 1999). In most cases, this species accounts for the highest percentage of parasitism in comparison to other parasitoid species, particularly in commercial fruits grown in agricultural areas (e.g., López *et al.*, 1999).

Augmentative biological control, the mass release of parasitoids at appropriate times and places, has been proposed as a new approach for fruit fly suppression (Knipling, 1992). *D. longicaudata* was considered a good candidate for this kind of control, since it is already established and methods for its mass production and release have been developed in different parts of the world (Sivinski, 1996). Burns *et al.* (1996) and Sivinski *et al.* (1996) reported a substantial reduction in mean trap capture of *Anastrepha suspensa* (Loew) in

Florida, in areas where *D. longicaudata* was augmentatively released. Camacho (1989, 1994) released both *D. longicaudata* and the pteromalid pupal parasitoid *Pachycrepoideus vindex* Rondani in Costa Rica and reported a significant reduction in the number of *C. capitata* subsequently captured in traps. In Hawaii, Wong *et al.* (1991) evaluated the effectiveness of augmentative releases of the closely related species *D. tryoni* against *C. capitata* and observed significant increases in parasitism in release areas.

Knipling (1992) and Barclay (1987) have argued that augmentative biological control can also be used in eradication programs in conjunction with the sterile insect technique. Such a combined strategy was tested against *C. capitata* by Wong *et al.* (1992). Based on the successful efforts by Wong *et al.* (1991, 1992) and Sivinski *et al.* (1996), we felt warranted to evaluate the effectiveness of augmentative releases of *D. longicaudata* for suppressing *Anastrepha* spp. populations in mango orchards in Chiapas, Mexico. We here report the results of this study.

MATERIALS AND METHODS

Description of the study area. The Soconusco region is located in southern Chiapas, Mexico. This region is characterized by its great ecological diversity (Deinlen, 1993). The area of mango production can be divided into two zones: (1) The commercial zone, with ca. 16,000 ha of orchards (CRSVFS-SAGAR, 1998), is located mainly in the coastal plain at an altitude of between 15 and 80 m above sea level. Other crops in this area are corn, soybean, and banana, in addition to cattle pasture and mangroves. None of these cultivated areas harbor many additional fruit fly host plants. (2) The marginal zone, where these experiments were carried out, is located between 60 and 180 m above sea level and harbors many wild and cultivated fruit fly hosts, such as Creole mango (*Mangifera indica* L.), grapefruit (*Citrus grandis* Osbek), sour orange (*Citrus aurantium* L.), sweet orange (*Citrus sinensis* Osbek), tangerine (*Citrus reticulata* Blanco), sapodilla fruit (*Manilkara zapota* Miller), hogplum (*Spondias mombin* L.), and guava (*Psidium guajava* L.). These hosts are found mainly in backyard gardens and orchards close to the Suchiate, Cahoacán, and Coatán rivers. Some commercial mango orchards are located in this marginal zone, where high fruit fly populations are common. This zone was selected, to enable useful comparisons in terms of the effect of augmentative parasitoid releases on fly populations.

Parasitoids. *D. longicaudata* parasitoids were produced at the "Moscafrut" mass rearing facility located in Metapa, Chiapas, according to the procedures described by Cancino (1997). Parasitized fruit fly pupae were packed in paper bags with sucrose as food, at a density of approximately 2500 pupae per bag. Bagged

pupae were placed in a dark room at $25 \pm 2^\circ\text{C}$ and $65 \pm 5\%$ RH for 5 days, until both males and females emerged. One thousand bags were prepared weekly, with an average emergence of 60%, equivalent to about 1500 parasitoids per bag, and a female:male sex ratio of ca. 2:1.

Parasitoid release plots. Parasitoids were released by air on a weekly basis using for the most part a Bell 206 helicopter (when not possible, a Cessna 210 was used). Releases were carried out over the entire mango season, a period of 35 weeks that begins with the flowering period (November) and finishes at the end of the growing season (July). In each of the 2 years, we worked in 4×4 km (=1600 ha) experimental plots. During the 1st year (1996), parasitoids were released in one plot while the other plot was used as a control. Both control and treated plots contained commercial mango orchards (Ataulfo cultivar) and backyard orchards in which a mixture of mango cultivars and other species of fruit trees were planted (e.g., citrus, guava, tropical plum, etc.). Backyard orchards were not subject to any agricultural management practices. During the 2nd year, treatments in each of the plots were reversed to allow comparisons on a spatial and temporal basis.

Approximately 940 parasitoids per hectare were released every week. This density was selected based on data from a previous test in Mazapa, Chiapas, Mexico, during which high levels of parasitism were achieved (W. Enkerlin, unpublished data). The 1st year, the release zone was located close to the village of Tuxtla Chico, which was 7 km away from the control zone in the village of Frontera Hidalgo. During the 2nd year the zones were reversed. As noted previously, these zones differed mainly in terms of the density of alternative hosts.

Monitoring of fly and parasitoid populations levels. Four sampling sites were established in the commercial orchards of each zone. Each site consisted of a 1-ha orchard. Three MacPhail traps baited with 250 ml of liquid protein (Captor 300) were used to monitor adult fly populations. Traps were serviced weekly for 38 weeks. To document the presence of parasitoids, three "sausage" bags were deployed in each orchard. These bags are yellow cloth bags, ca. 20 cm long and 7 cm in diameter, filled with diet and ca. 300 irradiated third instar *A. ludens*. To force larvae into a vulnerable position, a corn cob was placed in the center of the bag. Parasitism of fly larvae in these bags was used mainly as a detection tool to monitor parasitoid activity during the initial phase of parasitoid releases, when mango was flowering and fruits were not available. Finally, to determine fruit infestation and percentage parasitism levels, we collected infested wind-fallen fruits in each site. The number of larvae per fruit, weight of fruit, and percentage parasitism were determined in each

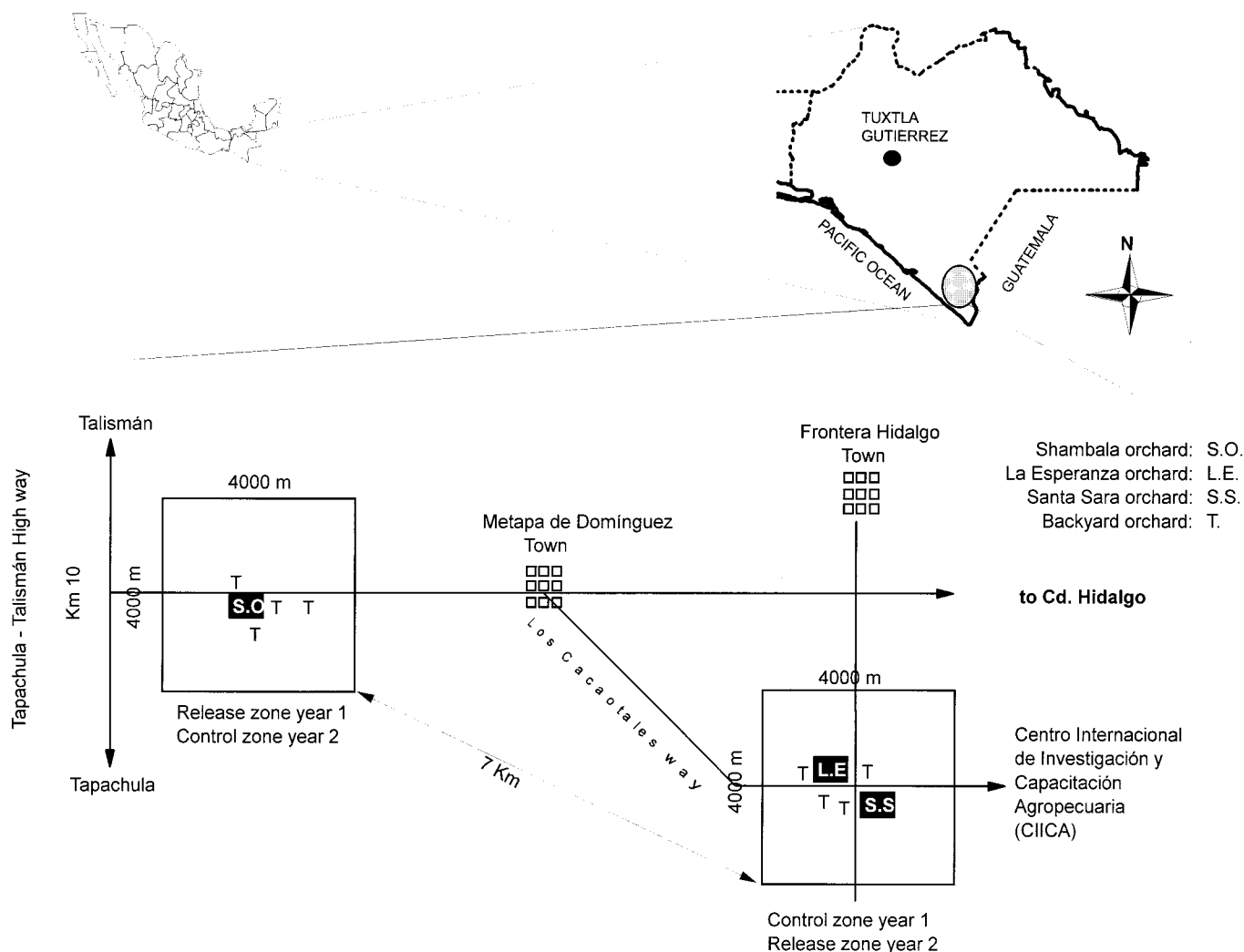


FIG. 1. Location of release and control zones (years 1 and 2) during the evaluation of *D. longicaudata* augmentative releases.

site. Samples consisted mainly of ripe fruits that showed evidence of fruit fly infestation. The number of fruits per sample varied from 1 to 30 depending on fruit availability. All sampling and trapping data were recorded on a weekly basis.

In each experimental zone, we also selected four similar backyard orchards (ca. 1–2 ha) close to commercial orchards (Fig. 1). Each backyard orchard was considered as a sample site. Three McPhail traps and three sausage bags were also used to detect the presence of adult flies and parasitoids.

All tephritid flies captured in the McPhail traps were identified and sexed in the laboratory. From the sausage bags, 100 fly pupae were selected at random and percentage parasitism was determined. Fruit samples were placed in Styrofoam boxes for 3–6 days and were subsequently dissected. Fly larvae were placed in 250-ml plastic containers with damp vermiculite to facilitate pupation. Percentage parasitism was calculated by dividing the total number of emerged parasitoids

by the sum of emerged flies plus emerged parasitoids (Wong *et al.*, 1991).

Statistical analysis. Student *t* tests were used to compare the number of flies/trap/day (FTD), percentage parasitism in fruits, percentage parasitism in sausage bags, the number of larvae/kg of fruit, and the number of adult flies emerged/kg of fruit. These comparisons were made for the same year between zones and for the same zone between years. Percentage data were transformed to arcsine square root before analysis. To compare suppression differences between *A. ludens* and *A. obliqua* populations, a χ^2 proportion analysis was made. The analyses were performed using Statgraphics 7.1 (Statgraphics, 1993).

RESULTS

Adult trapping. The effect of parasitoid releases on the number of flies captured in traps was significant when comparisons were made between years within

TABLE 1

Effect of Augmentative Releases of *D. longicaudata* on *Anastrepha* spp. Populations in Mango Backyard Orchards Located in Tuxtla Chico and Frontera Hidalgo Zones, during 2 Years of Releases

Parameters	Tuxtla Chico			Frontera Hidalgo		
	Year I release	Year II control	Significance	Year I control	Year II release	Significance
Flies/trap/day	1.08 ± 0.31	3.28 ± 0.59	*	1.17 ± 0.25	0.36 ± 0.09	**
% Parasitism in fruit	35.94 ± 4.65	3.94 ± 2.71	**	2.08 ± 0.72	41.22 ± 3.66	**
% Parasitism "sausage bag"	4.86 ± 0.62	0.59 ± 0.16	**	0.0	5.58 ± 0.94	**
No. larvae/fruit	2.32 ± 0.49	3.49 ± 1.03	NS	3.04 ± 0.81	1.52 ± 0.48	*
No. larvae/kg of fruit	10.51 ± 2.58	12.73 ± 2.39	NS	16.91 ± 4.40	9.70 ± 2.80	*
No. adult flies/kg of fruit	7.84 ± 0.93	10.27 ± 1.05	NS	12.23 ± 3.26	6.22 ± 2.35	*

Note. Values represent mean (±SE) for parameter.

* $P = 0.05$; ** $P = 0.001$; t test, $\alpha 0.05$.

each area. The degree of adult fly suppression in Frontera Hidalgo was highly significant (Table 1), with a 70% reduction in the number of flies captured. In Tuxtla Chico, the difference was also significant, with a 67% reduction. The difference between the two zones in the 1st year was not significant (t_{37} ; $P = 0.7853$). For the 2nd year, the difference between the two zones was highly significant (t_{37} ; $P = 0.001$). Spatial differences were independent of parasitoid releases.

Figure 2 shows mean adult capture and percentage parasitism. It is clear that *D. longicaudata* was able to parasitize and suppress fruit fly populations effectively

when mass released. Trap capture values in Tuxtla Chico were never greater than 6 flies/trap/day when parasitoids were released. In contrast, when no releases were made, the FTD index reached 16. In Frontera Hidalgo trap captures without releases reached a maximum of 5.5 FTD, whereas when releases were made, the FTD index was never greater than 1.7. The effect of *D. longicaudata* releases seemed thus to have been stronger in the Frontera Hidalgo zone.

Importantly, the effect of parasitoid releases differed according to fruit fly host species. Suppression was greater in *A. obliqua* populations than in *A. ludens*

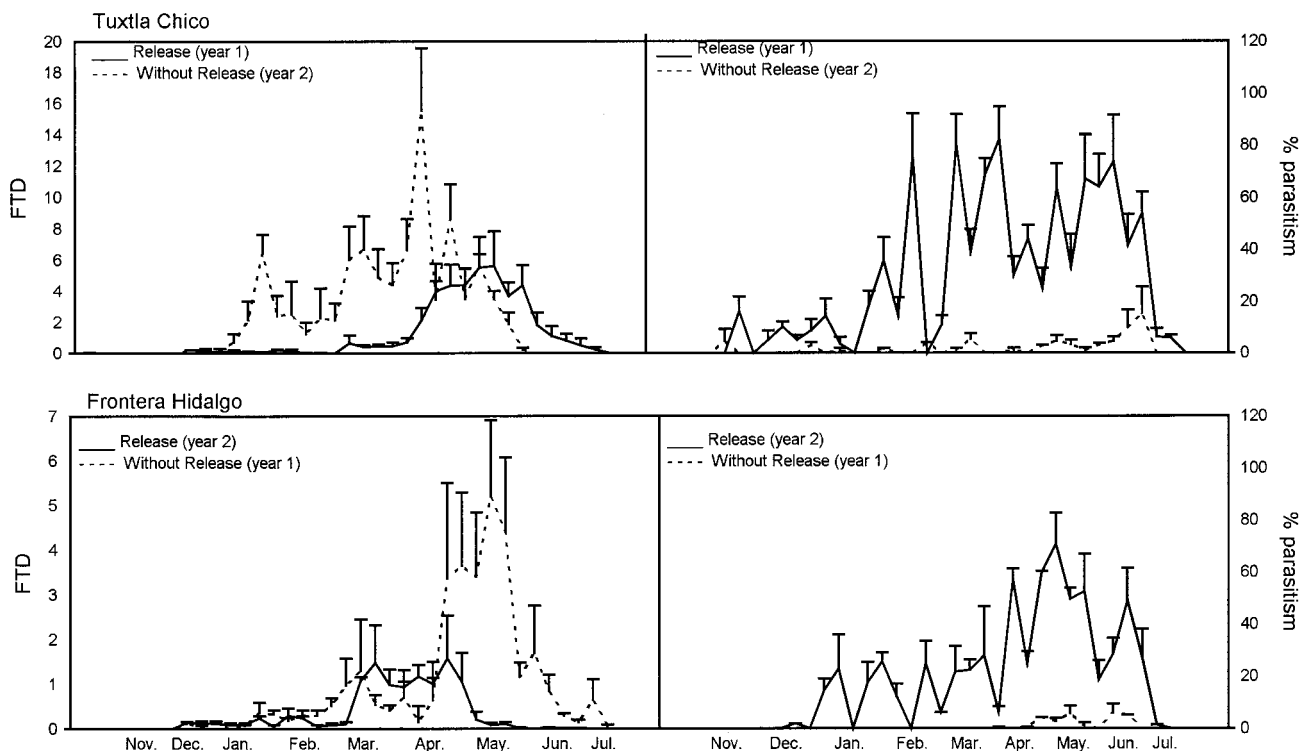


FIG. 2. Weekly *Anastrepha* spp. captures expressed as flies/trap/day (+SE) and percentage parasitism (+SE) in Tuxtla Chico and Frontera Hidalgo during the study period: effect of augmentative *D. longicaudata* releases.

TABLE 2

Patterns of Fly Infestation and Percentage Parasitism of *D. longicaudata* in Different Types of Sampled Fruits during Parasitoid Releases in Tuxtla Chico and Frontera Hidalgo Zones

Scientific name	Local name	Family	Average fruit weight (g)	Number of fruits	Sample weight (kg)	L/F	L/kg	% Parasitism
<i>Spondias mombin</i>	Hog plum	Anacardiaceae	16	977	16.35	1.09	65.13	63.80 ± 2.35
<i>Mangifera indica</i>	Creole mango	Anacardiaceae	141	2693	381.78	2.37	15.33	42.40 ± 4.37
<i>Mangifera indica</i>	Amate mango	Anacardiaceae	183	376	69	3.26	17.79	41.19 ± 9.29
<i>Mangifera indica</i>	Ataulfo mango	Anacardiaceae	247	1907	471.92	1.38	5.59	33.03 ± 5.71
<i>Mangifera indica</i>	Manila mango	Anacardiaceae	203	130	26.5	3.23	16.17	34.50 ± 9.54
<i>Psidium guajava</i>	Guava	Myrtaceae	87	72	6.3	1.97	19.70	17.18 ± 6.73
<i>Citrus grandis</i>	Grape fruit	Rutaceae	283	150	57.5	5.41	14.11	9.38 ± 11.12
<i>Citrus aurantium</i>	Sour orange	Rutaceae	193	269	52.1	7.85	38.89	8.02 ± 1.73
<i>Citrus sinensis</i>	Sweet orange	Rutaceae	261	749	195.5	1.90	7.27	2.37 ± 2.08
Total				7323	1275.25			

Note. L/F, larvae per fruit; L/kg, larvae per kg of fruit.

populations ($\chi^2 = 520$; $df = 1$; $P < 0.001$). This effect is observed for both trap captures and number of adults emerging from field-collected fruits (Table 3). *A. obliqua* was more abundant in Creole mango fruits (62.60%) than on Ataulfo mango. Adult captures were also higher in backyard orchards (58.25%) than in commercial orchards. In contrast, *A. ludens* was more abundant in the Ataulfo commercial orchards than *A. obliqua* (Table 4). We note that trap captures of both species in absence of parasitoid liberations followed a pattern similar to that described by Aluja (1993) (Fig. 3), with an initial predominance of *A. ludens* at the beginning of the fruiting season and a predominance of *A. obliqua* at the end of the season.

Parasitism. Percentage parasitism by *D. longicaudata* in fruits stemming from backyard orchards was significantly different when comparing release and no-release years within experimental zones and between zones for the same year (Table 1). This difference was observed during the whole experimental period (with the exception of those few weeks in which there were insufficient fruits to sample). Figure 2 shows the differences in weekly parasitism in both zones during the two releasing periods. Percentage parasitism in different fruit species or cultivars are shown in Table 2.

Clearly, hogplum (*S. mombin*) and Creole mango (*M. indica*) showed the highest average parasitism. Parasitism of larvae in sausage bags was also significantly different in release and no-release areas, although the levels achieved were lower than those recorded in fruit samples. In the 2nd year after parasitoid releases (Tuxtla Chico zone), no significant residual effects on parasitism levels were observed (Fig. 2).

Results from commercial orchards are not shown. No analysis was performed because the number of flies captured in McPhail traps and the number of infested fruits were very low. We believe that this was a consequence of the pest management practices used in these orchards (e.g., pesticide applications, disposal of infested fruit).

DISCUSSION

There are three important aspects of our results that, we believe, merit discussion. First, the suppression of fruit fly populations caused by augmentative parasitoid releases (nearly 70%) demonstrates the efficacy of augmentative biological control of fruit flies in areas surrounding commercial orchards. Second, the differences in population suppression when comparing

TABLE 3

Effect of *D. longicaudata* Parasitoid Releases on the Number of *A. ludens* and *A. obliqua* Adults, Captured in McPhail Traps or Emerging from Sampled Fruits in Control (C) and Release (R) Zones, during the 2-Year Study Period

	Release zone R	Control zone C	Ratio R/C	χ^2^a	P
Adults captured in traps					
<i>A. ludens</i>	4348	5858	0.74	520.27	0.001
<i>A. obliqua</i>	2511	6792	0.37		
Adults emerged from fruits					
<i>A. ludens</i>	1640	3552	0.46	106.47	0.001
<i>A. obliqua</i>	856	3062	0.28		

^a χ^2 , proportion analysis, $df = 1$.

TABLE 4

Differences between *A. ludens* and *A. obliqua* in Percentage of Emergence from Fruits Collected and Percentage of Captures in McPhail Traps in Both Ataulfo and Creole Mango Orchards

Fruit	Flies emerged from fruit		Capture of flies in McPhail traps	
	<i>A. ludens</i> (%)	<i>A. obliqua</i> (%)	<i>A. ludens</i> (%)	<i>A. obliqua</i> (%)
Ataulfo mango	69.52	30.47	71.89	28.11
Creole mango	37.39	62.60	41.35	58.65

A. ludens and *A. obliqua* highlight the effect that the type of fruit can have on the ability of parasitoids to successfully locate and attack developing larvae. Third, it is still necessary to determine the most effective parasitoid/fly ratio that would achieve the highest host suppression.

Fruit fly host abundance in areas surrounding commercial orchards may be of key importance in determining the effectiveness of parasitoid release programs (Aluja and Liedo, 1986; Aluja and Sivinski, 1999). In our study sites, many highly infested hosts were found

in backyard orchards, allowing fruit fly populations to increase. It is from these poorly managed orchards and from patches of wild vegetation that flies move to commercial orchards, where they can inflict severe damage. We therefore strongly believe that augmentative biological control programs must be aimed at suppressing fly populations in these "source areas." To illustrate, Aluja *et al.* (1996) found that 62.3% of fruit flies caught in McPhail traps placed in commercial orchards stemmed from traps located in border rows, which is an indication of immigration. Parasitoid releases in these marginal areas would be highly effective, since most of the fruit varieties grown by low-income farmers or produced by wild trees bear much smaller fruits than commercial varieties and therefore facilitate parasitization of larvae. Our data strongly support this conclusion. The highest impact of parasitoid releases was observed in backyard orchards and in small fruits with large seeds, such as hog plum (*S. mombin*) and Creole mango. This phenomenon (i.e., effect of fruit size on rates of parasitism) has been extensively documented by Sivinski (1991), Sivinski *et al.* (1997), and López *et al.* (1999) (see Table 2 for further evidence). Fruit size could also be correlated with the greater population suppression achieved in *A. obliqua* (compared to *A.*

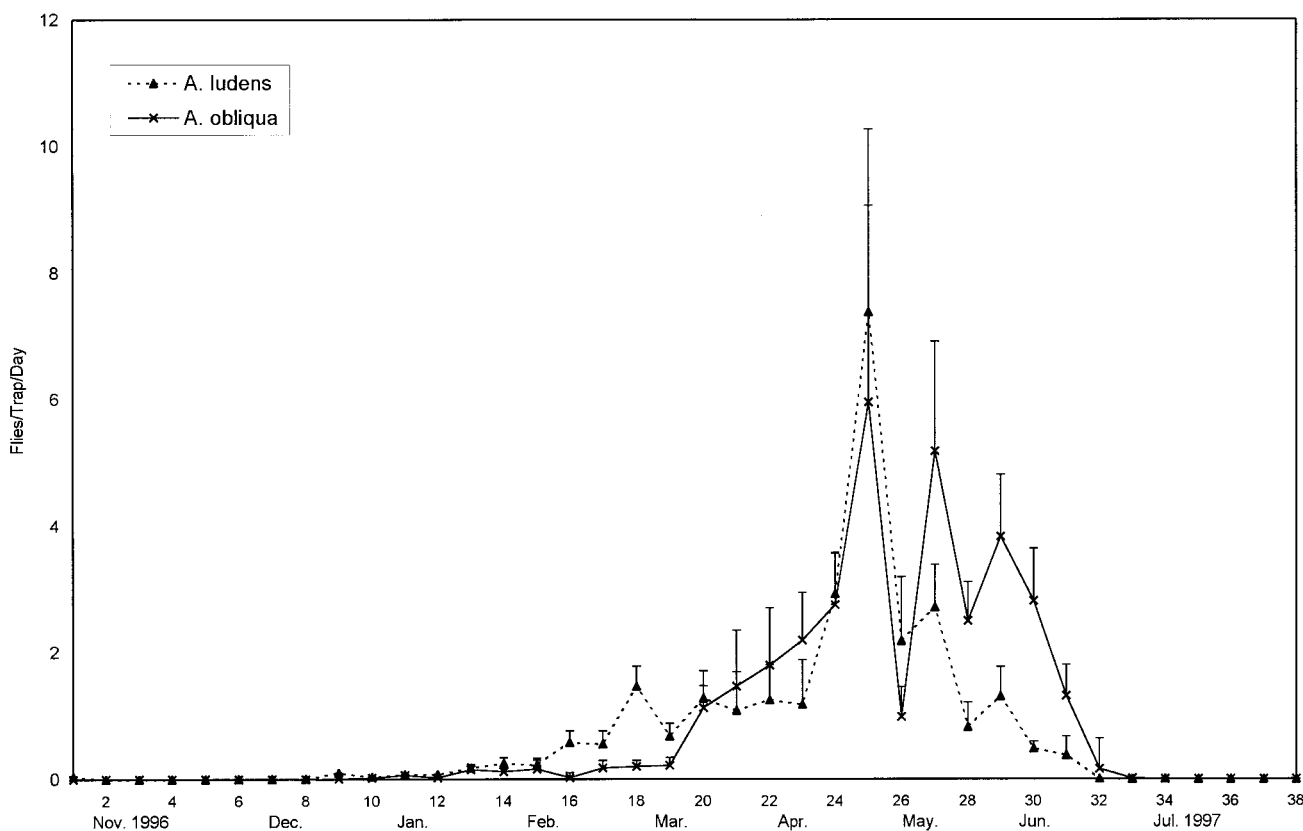


FIG. 3. Weekly *A. ludens* and *A. obliqua* captures in backyard orchards in the Tuxtla Chico control zone (no parasitoids were released here). Trap capture values are expressed using the FTD index (fly/trap/day + SE).

ludens) (Table 3). This species is generally associated with plants of the Anacardiaceae family, whereas *A. ludens* has a wider range of host plants (Aluja *et al.*, 1987; Norrbom and Kim, 1988). In our study, *A. obliqua* was found to be more abundant in the small Creole mangoes, whereas *A. ludens* was more common in the larger commercial Ataulfo cultivar (Table 4). Note that parasitism reached ca. 64% in hog plums and only 33.03% in Ataulfo mangoes (Table 2).

Fruit fly populations increased in both experimental zones over time, even with parasitoid releases (Fig. 3). This suggests that when host density is low, reduced parasitoid searching efficiency becomes a limiting factor, resulting in an increasing proportion of larvae escaping attack by the parasitoid. Low host population density may thus represent an effective form of refuge (Murdoch, 1994; Hochberg and Hawkins, 1994). Parasitism of *A. suspensa* by *D. longicaudata* in Florida was strongly positively density dependent (Sivinski *et al.*, 1996). Low parasitism by *D. longicaudata* in big fruits was observed despite the fact that this species has been considered to be relatively effective at attacking larvae feeding deep inside the fruit (Sivinski *et al.*, 1997) compared to other native parasitoids, such as *Doryctobracon aerolatus* (Szepligeti) and *Utetes anastrephae* (Viereck), also present in the study area.

Density of released parasitoids may be another key factor determining degree of fruit fly population suppression. To reach parasitism levels higher than 90%, Knippling (1992) suggested a ratio of four adult parasitoids to each adult fruit fly within the release zone, based on the premise that the number of parasitized hosts depends on the total number of parasitoids relative to the total number of hosts. However, it is difficult to estimate fruit fly densities, either by the number of fruits present in a highly diverse environment and the percentage of fruit infestation (Sivinski *et al.*, 1996) or through adult captures in McPhail traps, since there are no established criteria for relating the number of captured flies to absolute population density. Judging from McPhail trap captures, we estimated that density of flies in Tuxtla Chico was at least 2.5 times greater than in Frontera Hidalgo. Consequently, to achieve similar levels of fly suppression the number of parasitoids released would have to be increased proportionately.

Parasitoid releases were made by air in a random manner. Despite this, within several weeks, differences were observed in the incidence of parasitism in backyard orchards. This suggests that parasitoid dispersal was not homogeneous. Parasitoid dispersal might be strongly influenced by tree density, presence of fruits, and the degree of larval infestation in these fruits (J. Cancino *et al.*, unpublished data). This dispersion could have also been affected by the distribution of the release bags. One possible reason for the differences in percentage parasitism observed among

backyard orchards could be the fact that on some occasions bags fell outside the target orchards within the study zone or fell on sites where parasitism was not assessed. An alternative to parasitoid releases by means of bags could be the release of chilled adult insects, as recommended by Holler *et al.* (1996). The use of this method could result in a more uniform distribution of parasitoids in the field.

The levels of parasitism reported here could be underestimating the real effect of parasitoid releases. Picking fruits removes the larvae that they contain from subsequent exposure to parasitoids and can easily result in estimates that are only half of potential parasitism (Sivinski *et al.*, 1996). This is particularly a problem in estimating parasitism by *D. longicaudata*, since it forages extensively over fallen and rotting fruits (e.g., Purcell *et al.*, 1998). As Wong *et al.* (1991) have pointed out, fruit sampling may cause a considerable reduction in the density of fly larvae that could have been available for the parasitoids. Furthermore, percentage parasitism data per se may not always be a good indicator of the true patterns of mortality experienced by host populations (Van Driesche, 1983; Van Driesche *et al.*, 1991). Montoya *et al.* (2000) reported that under laboratory conditions when the parasitoid:fly ratio is high, substantial fly larvae mortality may occur as a consequence of superparasitism.

Adult trap captures were reduced from 1.17 to 0.36 in the case of backyard orchards in Frontera Hidalgo, where we assume a better parasitoid:host ratio was established. However, complete population suppression was not achieved. This may be due to one or a combination of the following reasons. First, there was a lack of complete isolation of the population in the experimental zones, even though we attempted to simulate a "small island" in the release area (1600 ha) by selecting mango orchards for sampling that were located in the center of each release zone. We do not know whether the captured flies were immigrants from the surrounding areas or whether they were the offspring of previous generations in this zone that were not suppressed by parasitoids. Second, the true parasitoid:fly ratio may have not been high enough, and this appears to be of key importance in the success of the release program according to Knippling's model (1992). Finally, and as noted before, large fruits may offer an effective refuge for the fruit fly larvae, and low host density may encourage parasitoid emigration.

Given the mobility of both the released parasitoids and the pests, we would like to emphasize the need for the large-area approach used in this experiment, which precludes the use of appropriate replicates and has natural experimental limitations. However, we believe that this trade-off between controlling for the effects of mobility and having replicates was needed and worthwhile.

Based on our results, we believe that if augmentative biological control of fruit flies is used in the proper manner and against well-isolated populations, or at least in large areas, the proposed approach might be highly effective and environmentally acceptable. Furthermore, if this kind of biological control is used in conjunction with other control strategies, such as the sterile insect technique and cultural control methods, this could result in significant and important synergistic effects on pest population suppression, as already noted by Barclay (1987), Knippling (1992), Wong *et al.* (1992), and Sivinski *et al.* (1996).

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